PACIFIC

Passive seismic techniques for environmentally friendly and cost efficient mineral exploration

D8.7 – PACIFIC symposium

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Duration	42 months	**Lead Beneficiary**	UGA

Description
The PACIFIC symposium will target all main stakeholders and aims to present the PACIFIC technologies and models as well as exchange with other experts about techniques for mineral exploration and mining.

Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive Summary

The PACIFIC project that started in June 2018, will be ending on 30th November 2021.

In that context, the PACIFIC Final Events were held at the University Grenoble Alpes (UGA), Coordinator of the project, in France, as well as online. They consisted in the Final Symposium taking place on 27th October 2021 and a Workshop dedicated to the Kallak experiment held on 28th October. While the first day was related to project outputs and preliminary results, combined with talks from external experts on the topic, the second day was focused on presenting the test of the 3D array for passive seismic tomography held at the Kallak deposit in Sweden.

In the framework of this event, a related conference in French open to the local public was also organised in Grenoble, focused on the challenges related to mineral resources in the context of the energy transition.

This document provides the programme of the event as well as a summary of each talk.

1 Introduction

The PACIFIC project gathers a consortium of nine partners spread over eight countries:

1. Université Grenoble Alpes (UGA)
2. Dublin Institute for Advanced Studies (DIAS)
3. Generation PGM Inc. (GEN)
4. SAS Sisprobe (SISP)
5. Beowulf Mining Plc (BEOW)

5.1 Jokkmokk Iron Mines Ab (JIMAB)

6. Geological Survey Ireland (GSI)

6.1 Economic and Social Research Institute (ESRI)

7. Institute of Mine Seismology (IMS)
8. ARTTIC (ART)

8.1 CIAOTECH Srl (CTECH)

9. Oy Fennoscandian Resources Ab (FRA).

To mark the end of 3.5 years of joint work, share the global results and enable discussions between partners and persons outside of the project, PACIFIC organised a Symposium in Grenoble on 27th of October 2021. For a practical issue, we decided to combine this event with the Kallak workshop, presenting the organisation and the first results of the Kallak experiment, on 28th October.

We chose to host the events at the University of Grenoble to facilitate the attendance of persons working at UGA or Sisprobe, persons involved or not in the project. In addition, Grenoble is a city easy to reach from other countries, due to its proximity to Geneva's and Lyon's airport, which would have been thus a good location if travelling were easier at the time of the conference.

Due to the COVID pandemic context, travelling between countries was still complicated and we thus chose a hybrid event with both a physical and an online option.

In addition, one of the expected impacts of PACIFIC was to improve the public awareness and acceptance of mineral exploration. Within this scope we decided to organise a public conference in the city centre of Grenoble on 27th October in the evening on the stakes of mineral resources in the energetic transition.

The PACIFIC Final Events (Symposium and Kallak Workshop) gathered 23 participants on site each day, while 31 had registered for online participation. The conference of 27th October evening open to the local public was a success as it gathered 38 participants. In addition to some of the French-speaking persons who had attended the symposium during the day, a group of students as well as locals attended the event.

2 Programme

PACIFIC gathered persons from different backgrounds and so it seemed important to start the Symposium with general talks on specific techniques at the origin of the PACIFIC research, thus giving a common knowledge to all participants before presenting our results, therefore helping to better understand them and put in context the improvements made during our project.

With that objective in mind, we decided to invite two external speakers:

Sarah Gordon from Satarla, to talk about sustainable mineral exploration, and Magnus Johansson from the Geological Survey of Sweden (SGU) to talk about the geology of Sweden.

2.1 PACIFIC Symposium, 27th October

Start	End	Session	Duration	Speaker
09:30	**10:00**	Welcome coffee	00:30	
10:00	**10:10**	The PACIFIC project	00:10	Noélie Bontemps (University of Grenoble, ISTerre)
10:10	**10:40**	Overview of the characteristics of ore deposits + acoustic properties of rocks and ores	00:30	Nicholas Arndt (Sisprobe)
10:40	**11:10**	Methods used to explore for ore deposits	00:30	John McBride (Generation)
11:10	**11:40**	Seismic method for exploring the Earth's crust	00:30	Christopher Bean (DIAS)
11:40	**12:10**	Passive seismic imaging	00:30	François Lavoué (UGA)
12:10	**13:10**	Lunch break	01:00	
13:10	**13:55**	Behaviour, attitude and communication; information sharing and public understanding in the mining sector	00:45	Aoife Braiden (GSI) and Olga Poluektova (ESRI)
13:55	**14:25**	Sustainable mineral exploration	00:30	Sarah Gordon (Satarla)
14:25	**15:15**	Overview of Marathon experiment in Canada (part 1)	00:50	UGA and DIAS
15:15	**15:35**	Coffee break	00:20	
15:35	**16:25**	Overview of Marathon experiment in Canada (part 2)	00:50	DIAS and UGA
16:25	**16:45**	Overview of other experiments (Kallak, Kaiserstuhl, Las Cruces)	00:20	Sophie Beauprêtre (Sisprobe)
16:45	**17:05**	Passive seismic as an exploration tool : the business case	00:20	Dan Hollis (Sisprobe)

Start	End	Session	Duration	Speaker
17:05	**17:20**	Contributions from the Scientific Advisory Board	00:15	PACIFIC Scientific Advisory Board
17:20	**17:30**	Closing of the symposium - major results	00:20	Florent Brenguier (UGA) / Nicholas Arndt (Sisprobe)
Evening conference in downtown Grenoble on 27th October (session in French):				
20:00	**21:30**	Les enjeux des ressources dans la transition énergétique	*01:30*	*Bruno Goffé, CNRS*

2.2 Kallak Workshop, 28th October

Start	End	Session	Duration	Speakers
09:00	**09:20**	Geological context of Northern Sweden	00:20	Magnus Johansson (Geological Survey of Sweden)
09:20	**09:40**	Geological overview of the Kallak Iron ore deposit	00:20	Rasmus Blomqvist (Beowulf Mining)
09:40	**10:00**	Kallak planning and objectives & development of sensors	00:20	Gerrit Olivier (IMS) / Sophie Beauprêtre (Sisprobe)
10:00	**10:20**	Problem with Permitting – Facts vs Fiction - Reindeer Herding, Regional Governments and Coalition Politics	00:20	Kurt Budge (Beowulf Mining)
10:20	**10:40**	Coffee break	00:20	
10:40	**11:00**	Results of the first array	00:20	Sophie Beauprêtre (Sisprobe)
11:00	**11:20**	Use of a 3D array	00:20	Daniela Teodor (UGA)
11:20	**11:40**	Operation in summer 21 & preliminary results	00:20	Gerrit Olivier (IMS) / Sophie Beauprêtre (Sisprobe)
11:40	**12:00**	Q&A session / Conclusion	00:20	Nicholas Arndt (Sisprobe) / Noélie Bontemps (ISTerre)
12:00		End of the workshop - Lunch		

3 Communication around the events

We communicated the different events through different channels depending on the targeted public.

3.1 Symposium and Kallak Workshop

We announced the Symposium and the Kallak workshop through common channels (H2020 projects working on similar topic, Twitter, ResearchGate, PACIFIC website). In addition, the partners also advertised within their company/university (people from ISTerre (UGA) and IMS outside of the project joined these two events).

We also invited the master students in geophysics and geology of UGA to attend the seminars, but their schedule was already planned and full at the time of the announcement.

3.2 Bruno Goffé's public conference

Visuals (flyers, poster) were created to advertise around this conference. These visuals were displayed in student libraries, at the tourist office, museum, etc. to reach the population that could be interested by the conference.

We also posted information about the event on the website of the journal Dauphiné libéré, the observatory of Grenoble (OSUG) and the ISTerre website.

4 PACIFIC Symposium

The following sections describe the content of the talks given during the symposium.

4.1 The PACIFIC project, Noélie Bontemps (University of Grenoble, ISTerre)

Noélie Bontemps provided a first introduction of PACIFIC, presenting the project consortium, rationale, innovative approach and objectives, as well as the two techniques and test sites, work plan and expected impacts. This presentation was based on PACIFIC_Project presentation_2021.

4.2 Overview of the characteristics of ore deposits + acoustic properties of rocks and ores, Nicholas Arndt (Sisprobe)

Nick Arndt presented an overview of ore deposits and the acoustic properties of rocks and ores and how passive seismic can act as a mineral exploration tool. He explained the differences between petroleum and mineral exploration as passive seismic techniques were developed for fundamental research and in the oil & gas industry. Ore minerals have various seismic velocities depending on which it will be more or less appropriate to use ambient noise surface wave tomography (ANSWT).

In PACIFIC, the goal was to extract body waves from ambient noise to image the gabbro intrusion that hosts the mineralization at the Marathon site in Canada, and to use a multi-array approach with body waves and extra noise sources to image large, high-velocity iron deposits at the Kallak site in Sweden.

4.3 Methods used to explore for ore deposits, John McBride (Generation)

John McBride first explained why mineral exploration is necessary and how it is affected by the location of mineral deposits. Consumption continues to grow, which is driving the demand for metals.

While exploration started thousands of years ago, first with salt, there is nowadays a stronger and stronger demand for copper as the society is moving to electrification. There is also a deficit for zinc, nickel, lead and other basic metals so prices are skyrocketing. Mining is not happening everywhere in the world as resources are not evenly distributed. Global demand is continuously growing but exploration goes in cycles, which creates a lag time between when it is needed and discovered. Most exploration is for gold so there is an even lower success rate for other metals. There are various challenges in discovering a deposit that leads to mining lower and lower grade deposits.

John McBride then presented the exploration methods, which involve geology, geochemistry, geophysics, drilling and machine learning. What is new is that we are more and more relying on computers to process data (using machine learning or data mining).

4.4 Seismic methods for exploring the Earth's crust, Christopher Bean (DIAS)

Chris Bean explained the rheology of the crust and why we explore it. There are two main sets of seismic waves: body waves (P or S waves) and surface waves (Love and Rayleigh waves). It is important to connect seismic waves to rock moduli.

Different exploration seismic methods and various seismic sources can be available, such as: explosions in boreholes, vibroseis, airgun, weight drop, hammer, earthquakes. Body wave imaging is usually focused on P-waves but it is not the only option.

Chris Bean explained the difference between seismic reflection and refraction and presented body wave tomography, crosshole travel time/waveform tomography, as well as surface wave analysis. A wave with different frequencies is travelling at different speeds.

4.5 Passive seismic imaging, François Lavoué (UGA)

François Lavoué presented the concept of seismic interferometry, which implies you record noise at two different stations and cross-correlate, thus recovering Green's functions. He explained how Green's functions extracted from noise cross-correlations are dominated by surface waves. One direct application is for Ambient noise surface wave tomography (ANSWT). Then he presented how to extract and use body waves for passive imaging with the example of train-induced seismic noise.

4.6 Behaviour, attitude and communication; information sharing and public understanding in the mining sector, Aoife Braiden (GSI) and Olga Poluektova (ESRI)

Aoife Braiden and Olga Poluektova presented work done in PACIFIC in relation to Social Acceptance and Perception of Risk for mining activities. Two elements of the work were presented: a generalised survey to assess opinions of mining & exploration in Ireland (by GSI) and two experiments to assess how people comprehend information, assess risk & make decisions (by ESRI).

The GSI questionnaire was related to underground mining for metallic minerals only with questions designed to be applicable to other countries/regions. Participants were asked about their experience of mining/exploration, what they consider to be main negative and positive aspects of mining and about their awareness of active underground mines in Ireland. 60% had no awareness of mines in Ireland although Tara mine is the second largest lead/zinc mine in Europe (but it is underground so not very visible). Then participants were asked about their attitude towards a new mine in the country or more locally, their trust in the enforcement of mining regulation/legislation in Ireland, their perception about companies developing new mines, whether foreign or Irish, or about perceived risks of new underground mines. Generally, there was no strong opinion on a new mine, but there would be more opposition locally than nationally. Participants were also questioned about their level of trust depending on who provides the information.

Regarding the two computerised experiments investigating how the method of online information provision affects people's comprehension and evaluation and the impact of the order/format of information, early commitment and personal values matter significantly. Participants were generally more positive about mining-related activities than expected. It appeared that the type of information received in first instance (i.e. positive or negative), and personal values and attachment to place clearly matter, and that negative information is more impactful and difficult to counteract.

More detailed results are presented in D6.4 – Results from standard polls (background knowledge) and local questionnaire.

4.7 Sustainable mineral exploration, Sarah Gordon (Satarla)

Sarah Gordon is the founder and CEO of Satarla Risk Management (consulting company), and of the non-profit movement Responsible Raw Materials. She introduced aspects of responsible mining and exploration. It would be possible to achieve a zero-carbon production, but it would have a negative impact elsewhere, so we need to seek balance. He presented the Sustainable Development Goals (SDGs) defined in 2015 (see The Global Goals) and the concept of ESG (Environment Social

Governance). There is an increasing gap between supply and demand. Mining is often seen as a "nasty" industry. However, we need to increase mining, but in a responsible way.

4.8 Overview of Marathon experiment in Canada, UGA and DIAS

The first PACIFIC experiment was conducted at the Marathon deposit in Canada, which is the largest alkaline complex in north America.

Charles Beard (UGA) first presented the geology of the Marathon Cu-Pd Deposit.

Then Laura Pinzon-Rincon (UGA) introduced the Marathon seismic dataset, including the Ambient Noise Surface Wave Tomography and standard cross-correlation method.

In a third part, Daniela Teodor (UGA) presented her work related to high-frequency surface wave tomography.

Work on seismic interferometry using train signals was then explained by Laura Pinzon-Rincon (UGA).

Part 5 of the presentation dealt with interfaces from ambient seismic noise, by Yihe Xu (DIAS).

Meysam Rezaeifar (DIAS) introduced the CMP-CC (Cross–Correlation + Common-Mid Point) approach that was applied on the train signal, using the timing of the train as main source.

Diako Hariri (DIAS) explained the possibility of retrieving reflection arrivals from passive signals.

Finally, Charles Beard (UGA) compared the interpretation of the seismic models.

More details about the Marathon experiment can be found in the following public reports:

PACIFIC_D3-1_Deployment complete

PACIFIC-D3.2_Successful extraction of body-wave data

4.9 Overview of other experiments (Kallak, Kaiserstuhl, Las Cruces), Sophie Beauprêtre (Sisprobe)

Sophie Beauprêtre presented the four other experiments conducted in PACIFIC besides Marathon: one at the second test site in Kallak, Sweden (multi-array method, further detailed during the dedicated Workshop on day 2), as well as three experiments performed through clustering with other projects. The first joint experiment took place at the Las Cruces Mine in Spain, in collaboration with the other H2020 project INFACT (Innovative Non-invasive & Fully Acceptable Exploration Technologies). The second one was organised with the H2020 project HiTech AlkCarb (New geomodels to explore deeper for High-Technology critical raw materials in Alkaline rocks and Carbonatites) at the Kaiserstuhl volcano in Germany. The last test was related to drilling as source and held in Freiberg, Germany. With these experiments of the passive seismic method with different survey geometries/sources/geological settings/sensors, PACIFIC partners have learned lessons about acquisition planning and design, the importance and impact of the distribution of sources as well as the impact of topography.

More details about the clustering activities can be found in:

PACIFIC_D7.1_Clustering Plan_v1

PACIFIC_D7-2_Report on joint events with other research projects in the first year

PACIFIC_D7-3_Report on joint events in the second year

D7.4 about the third year will soon be available at https://www.pacific-h2020.eu/media/#tabsid|1.

4.10 Passive seismic as an exploration tool : the business case, Dan Hollis (Sisprobe)

One of the objectives by project end is for the PACIFIC consortium to deliver a Business and Exploitation Plan. To this end, partners have been working on defining a business case for the use of passive seismic and key exploitable results for the project. A market analysis was conducted and a questionnaire was sent out to 25 companies, which led to two interviews to gain further insight of potential users' perspective.

4.11 Contributions from the Scientific Advisory Board

The following members of PACIFIC Scientific Advisory Board shared their views on the project:

- Richard Herrington, Economic geologist, Natural History Museum, London
- Chris Juhlin, Geophysicist at Uppsala University
- Gordon Chunnett, Consultant, Cape Town, South Africa.

Richard Herrington noted the geological applicability of the passive seismic technique in different domains and asked to comment on progress so far. Nick Arndt from Sisprobe explained that with the Marathon experiment, partners realised the limits of operating at a site with hard rocks, which provided limited contrast in lithology. Cover mapping as shown in Las Cruces can have a very useful application. Charlie Beard (Sisprobe/UGA) added that they were first targeting the deposit scale while the technique is sensitive for higher scale and economical.

Richard Herrington asked to comment on the different types of ambient sources. Ocean swells are pretty advantageous because they provide low frequencies and travel a long distance. But if looking for something very shallow, human activity is needed.

Gordon Chunnett considered a fantastic job was done, with much progress in the past two years. In Africa there is an array set up as a sequence, where PACIFIC results will help much.

Chris Juhlin commented that the surface wave seems to work very well, better than the body wave. But partners should not give up on the body wave that could work better in the right location.

4.12 Closing of the symposium, Florent Brenguier (UGA)

Florent Brenguier concluded the day, highlighting the fact that diverse presentations were held. Much has been achieved at a technical level, although the overall goal was not reached as successfully as expected, for several reasons including the choice of test site. But partners have still learned much and done significant progress with other joint activities. PACIFIC will be a stepping stone for future studies as found more source waves not expected before (cement factories producing huge body waves). Still a very active field of research, almost 40 on this topic only in Grenoble. Muchmore results expected in coming years.

Nick: interesting input for social acceptance, looking forward to booklet.

4.13 Conference in French: « Les enjeux des ressources dans la transition énergétique » (The challenges of resources in the energy transition), Bruno Goffé (Emeritus Director of Research at CNRS)

In the context of the upcoming COP26 in Glasgow, Bruno Goffé explained how climate change has been happening in parallel to economic and population growths in the past centuries. The energy transition we are now targeting to limit its impact however requires a more substantial use of metals. Technology helps increasing production but there are limitations to this, such as thermodynamics, the amount of energy, environmental impacts and the opposition to mining. Solutions rely in recycling

metals more efficiently, using naturally available hydrogen, generalising fair and sustainable mining practices, investing locally, not completely giving up on carbon and reducing our energy consumption.

A recording of the conference is accessible publicly here: https://www.youtube.com/watch?v=AL19ZhuNupI.

5 PACIFIC Kallak workshop

The following sections describe the content of the talks given during the Kallak workshop.

5.1 Geological context of Northern Sweden, Magnus Johansson (Geological Survey of Sweden)

As introduction to the Kallak Workshop, Magnus Johansson presented the geological context of the area where the Kallak experiment was performed (northern Sweden). An overview of the different national and regional geological units addressing their development and relations in a historical perspective, as well as ore forming processes and occurrence in North Sweden was given. Sweden has long been famous for its high quality steel, especially in Germany. The country hosts 90% of iron production in the EU but the tonnage is still very limited compared to Australia or Brazil. There is a strong history of mining and this has had a huge impact on Swedish state finances and industrial development. Sweden has a significantly different geological setting and big potential compared to Europe as a whole with abundant mineral and ore deposits and critical raw materials available. This is reflected in the high amount of investments in mining and prospecting, despite of Sweden representing a comparably small land area by international measure. In spite of a promising geological setting and a number of unexploited mineral resources of high importance, there are currently still only 12 active mines. For more than a decade, developing new deposits and projects has generally proven to be very difficult, among others due to legislation, environmental protection and public opinion reasons. This is clearly shown in the yearly Policy perception index of Fraser institute, where Sweden has dropped significantly.

5.2 Geological overview of the Kallak Iron ore deposit, Rasmus Blomqvist (Beowulf Mining)

Beowulf Mining is a junior exploration company based in UK and Sweden. It is currently working on three deposits among which Kallak, as well as on graphite projects in Finland.

Rasmus Blomqvist presented an overview of the Kallak Iron Ore Deposit and provided details on the regional and local geology, deposit type, mineralisation, deposit scale deformation and structures. The site is made of three deposits, consisting mostly in a mix of haematite and magnetite.

5.3 Kallak planning and objectives & development of sensors, Sophie Beauprêtre (Sisprobe) / Dolf Bredenkamp (IMS)

Sophie Beauprêtre presented the objectives and planning of the Kallak experiment. Two types of arrays were deployed: one at the surface and one in drill holes, using special geophones developed in PACIFIC. The plan was to first test the openness of the boreholes, then to cement geophones in the boreholes, install the two arrays, use drilling and finally remove the sensors. The first plan was drafted in 2020 and had to be updated in 2021 as the experiment was postponed due to the Covid-19 pandemic. Changes occurred as some boreholes were plugged, collapsed or intersected strongly flowing underground water, which led to issues to cement, while due to difficulties associated with drilling, its noise was replaced by that of a compactor and cars driving. The experiment has been completed, with acquisition finished early October.

Dolf Bredenkamp explained further the application and specifications, geophone selection and configuration and noise considerations.

5.4 Problem with Permitting – Facts vs Fiction, Kurt Budge (Beowulf Mining)

As explained by Kurt Budge, Beowulf Mining was first involved in Kallak in 2006 and obtained a first permit in 2014. The company has been dealing with government changes and then pandemic issues. Mining tends to have a bad reputation, although reindeer herding already coexists with controlled industrial development in Sweden, not only mining. The company is proposing economic development in a remote area and started a journey towards ESG (Environment Social Governance). They have learnt how important it is to be transparent in communications and to meet people locally.

5.5 Results of the first array, Sophie Beauprêtre (Sisprobe)

Sophie Beauprêtre first presented the geological context and area of interest at the Kallak deposit. She then explained how ambient noise surface wave tomography was used, presenting the array design and seismic data recording, the beamforming, cross-correlation sections and depth inversion parameters. She also provided a comparison with existing geological models. The resolution was poor due to the array geometry.

5.6 Use of a 3D array, Daniela Teodor (UGA)

Daniela Teodor presented the trial data set studied so far to prepare the analysis of data from the Kallak experiment. Work performed was related to the borehole to surface cross correlations.

5.7 Operation in summer 21 & preliminary results, Dolf Bredenkamp (IMS) / Daniela Teodor (UGA)

Dolf Bredenkamp presented the operations conducted in September 2021. Both a vertical and surface array were installed at the test site. He provided further details about the sensor installation and cementing process.

Daniela Teodor presented in more detail the surface deployment step and first results from the data recorded, through power spectral densities and spectrograms. Further work on correlation of borehole to surface data will be performed by end November (PACIFIC project's end).

5.8 Q&A session / Conclusion, Nicholas Arndt (Sisprobe) / Noélie Bontemps (ISTerre)

Nick Arndt and Noélie Bontemps hosted the last session during which questions from the audience were answered.

6 Acknowledgments

Apart from participation from the partnering organisations, PACIFIC would like to thank the members of its Scientific Advisory Board (SAB) for their participation:

- Wolfgang Maier, Economic geologist at University of Cardiff
- Richard Herrington, Economic geologist, Natural History Museum, London
- Martin Mai, Geophysicist, King Abdullah University of Science and Technology, Saudi Arabia
- Chris Juhlin, Geophysicist at Uppsala University
- Gordon Chunnett, Consultant, Cape Town, South Africa

PACIFIC partners are also grateful for the participation of:

- Two speakers external to the project who broadened the event perspective thanks to their talks: Sarah Gordon, Satarla and Magnus Johansson, Geological Survey of Sweden
- The European Commission (EC)
- The Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Coordinator of the INFACT project involved in clustering activities with PACIFIC.

7 Conclusion

The PACIFIC Final Events contributed to the dissemination of the project preliminary results. The last public reports will soon be available at https://www.pacific-h2020.eu/media;

After the project ends and the website closes, the final publishable summary and results including public reports and publications will remain available on the European Commission's Cordis platform: https://cordis.europa.eu/project/id/776622.